ARMY RESEARCH LABORATORY

Preliminary Design of a Range Correction Module for an Artillery Shell

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13. ABSTRACT *(Maximum 200 words)*

With the advances in microelectronics, miniature motor technology, and sensor technology, the reality of a Low Cost Competent Munition (LCCM) trajectory correction module is conceivable. The U.S. Army Research Laboratory (ARL) and the U.S. Army Armament Research, Development, and Engineering Center (ARDEC) have been working on various LCCM concepts. The LCCM concept dictates that the design of a trajectory correction module will fit into an artillery shell like any of the fuzes used by NATO.

This report represents an initial design process to identify potentially critical problems in the mechanical design of a trajectory control device. The design process will concentrate on the current level of technologies and the electro-mechanical requirements for a D-ring range correction module. The D-ring correction module is a one-dimensional, self-correction device concept for providing sufficient change in drag, to achieve the needed correction, given the constraints of size, power, and other necessary components and technologies. An LCCM range correction module appears to be a very viable concept without requiring aggressive technologies or high-risk approaches. The efficient use of the available volume for electrical and mechanical components will be crucial.

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1. INTRODUCTION

The primary purpose of the Low Cost Competent Munitions (LCCM) program is to improve the effectiveness of indirect fire support from cannon artillery (Sicignano 1995). With the advances in microelectronics, miniature motor technology, and sensor technology, the reality of a trajectory correction device is conceivable. The LCCM concept dictates that the design of a trajectory correction device will fit into an artillery shell, much like a standard NATO fuze would. Concepts that are currently being studied by the U.S. Army Research Laboratory (ARL) and the U.S. Army Armament Research, Development, and Engineering Center (ARDEC) are shown in Figure 1. The first LCCM device has been technically demonstrated and involves global positioning system (GPS) transponder technology. The GPS processing of the projectile's position occurs on the ground. The other concepts will require combinations of a GPS receiver/antennae/inertial measurement unit (IMU), a central processing unit (CPU), a maneuver mechanism, fuze function components, and a power source.

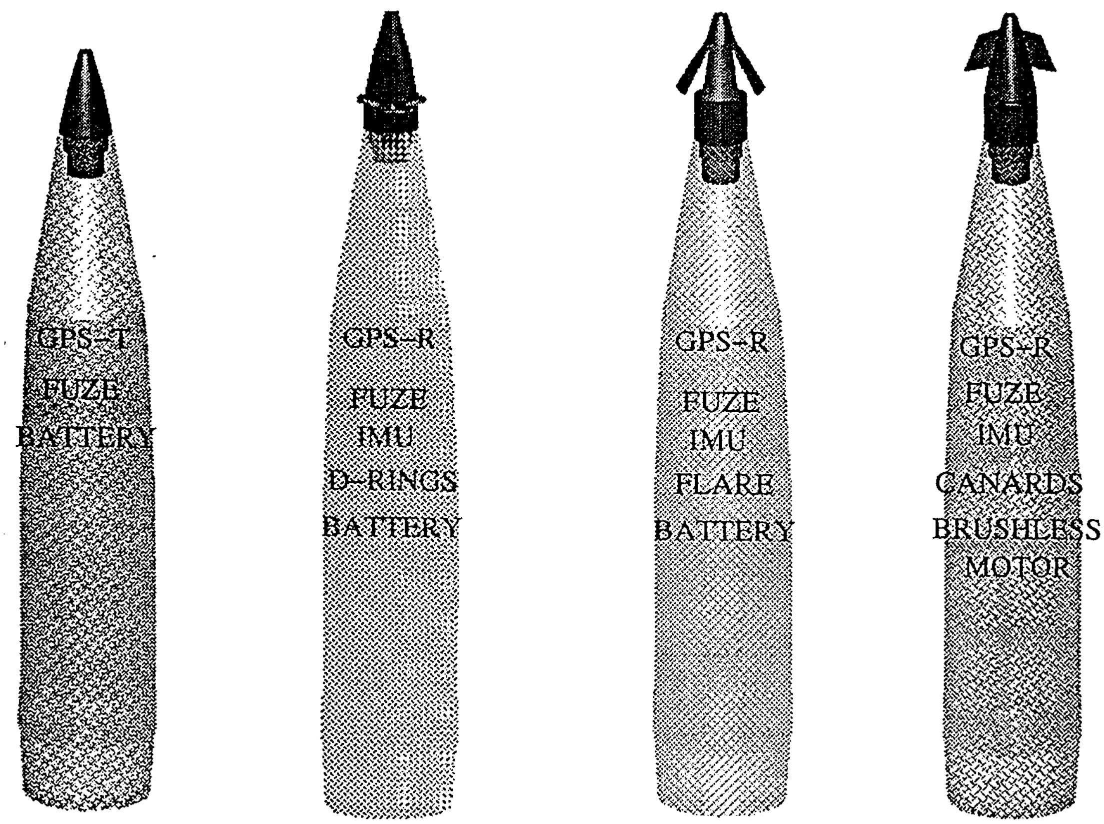

Figure 1. LCCM concepts.

This report represents an initial design process to identify potentially critical problems in the mechanical design of a trajectory control device. The design process will concentrate on the current level

of technologies and the electro-mechanical requirements for a D-ring range correction module. The D-ring correction module is a one-dimensional, self-correction device concept for providing sufficient change in drag given the constraints of size, power, and other necessary components and technologies. This report studies the concept as a single correction or a multiple correction application. This report does not conclude a single or best design. Note: this concept is also under consideration in the United Kingdom (Beattie 1995).

2. CONCEPT

2.1 <u>Adaptability</u>. One of the main objectives of the LCCM concept is to contain all of the mechanical and electrical components in the volume of a fuze that can fit into a variety of artillery shells used by NATO countries. The intent is simply to replace (in the field) the standard fuze with an LCCM trajectory control module, and not to produce any changes within the ogive of an artillery shell. (Discussion on the overall volume will be provided in section 3.)

Figure 2 depicts the LCCM D-ring range correction concept and how it will mate with the ogive. The aft part of the module body will fit close to the mouth of the expulsion cup just like a standard fuze. The aft part of the module was modeled after the M577 fuze, thus assuring adaptability to existing expulsion systems. The 1-inch extension maintains that the projectile length remain less than 1 meter in length.

2.2 <u>Range Correction Concept</u>. The purpose of the D-rings is to increase the drag of an artillery shell when desired. When deployed, the D-rings will symmetrically increase the frontal area of the fuze; therefore increasing drag. Brandon and Jara (1995) have made estimates of the percent change in drag as related to increases in frontal area. Before deployment of the D-rings, the frontal area of the fuze will resemble the figure on the right of Figure 3, with 65 mm being the largest diameter. When deployed, the frontal area will resemble the figure on the left of Figure 3. The spread of the D-rings in Figure 3 is 80 mm.

A concept of a D-ring can be seen in Figure 4. The deployed D-rings, with a spread of 80 mm, increases the frontal area by 1.57 times. If the D-rings were to be extended further, such that the spread was 100 mm, the increase in frontal area is approximately 2.18 times. A comparison of the frontal areas is found in Table 1. The initial study by Brandon and Jara (1995) has indicated that reasonable maneuver authorities can be achieved for frontal areas of 7.2 in^2 (46.5 cm^2) and 10.0 in^2 (64.2 cm^2).

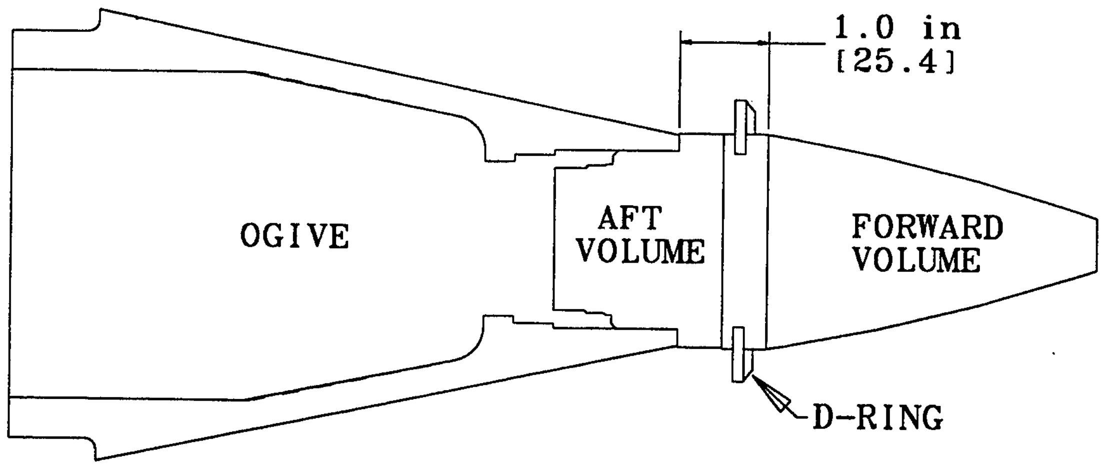

Figure 2. LCCM D-ring range correction concept and how it will mate with the ogive.

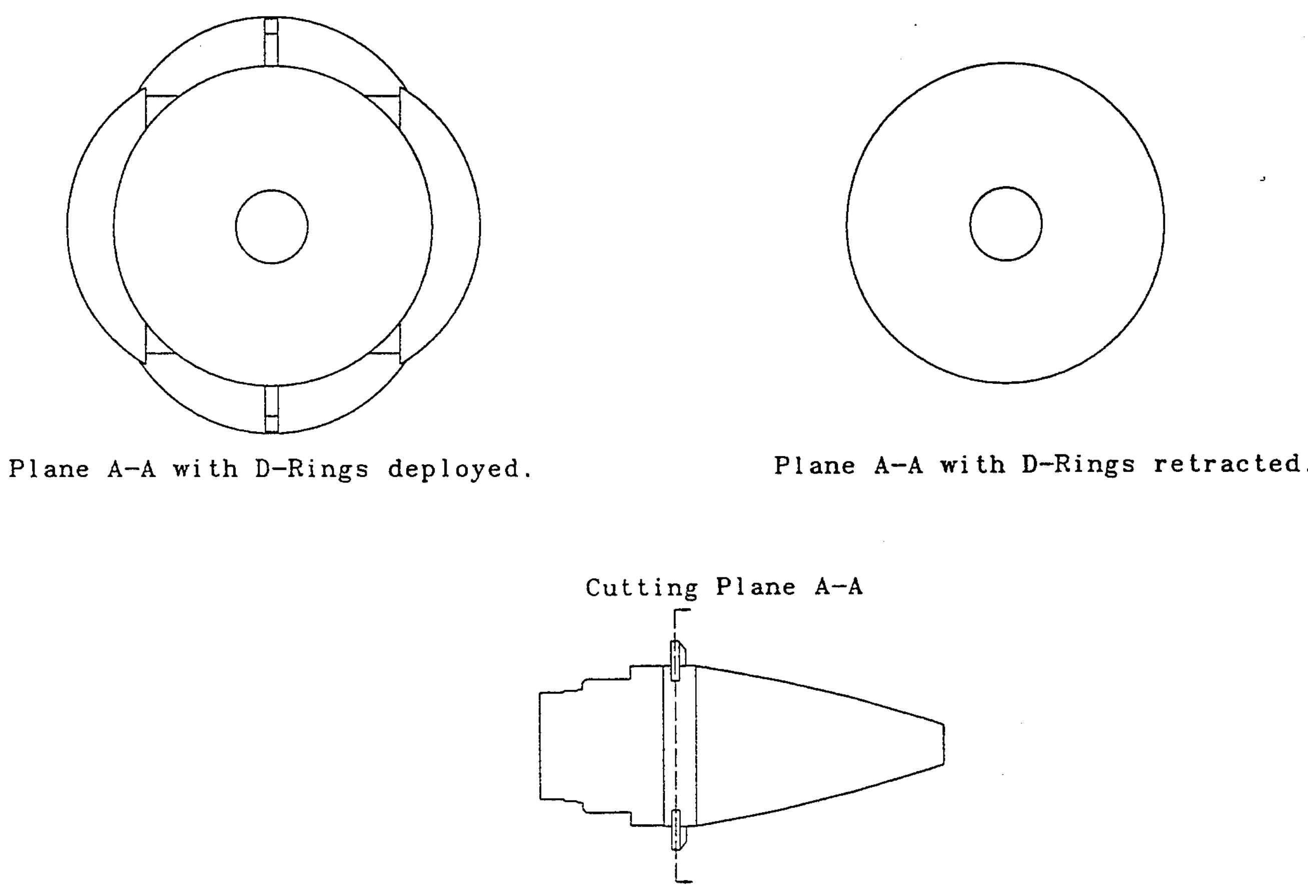

Figure 3. Plane A-A with (a) D-rings deployed, (b) D-rings retracted, and (c) the cutting plane.

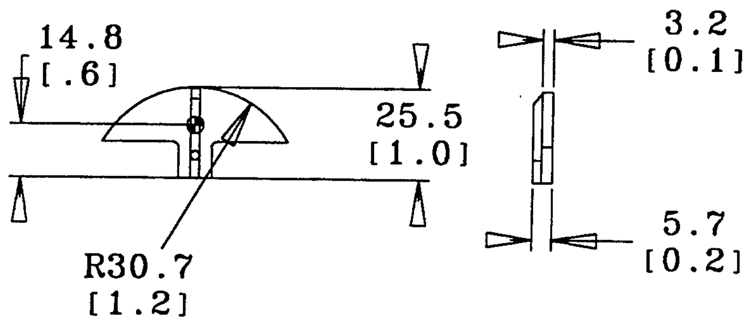

Figure 4. Concept of a D-ring.

Table 1. Comparison of Frontal Areas

Configuration	Frontal Area (in^2 [cm^2])
Fuze ogive alone	4.6 [29.7]
Fuze ogive with D-rings, spread = 80 mm	7.2 [46.5]
Fuze ogive with D-rings, spread = 100 mm	10.0 [64.2]

2.3 Actuation of D-Rings. The objective of designing the actuation of the D-rings was to minimize the number of moving parts and to use the least amount of volume. This concept employs cam actuation to deploy and retract the D-rings. The cam actuation concept, as seen in Figure 5, consists of a cam plate that allows the offset pins to slide back and forth in the grooves contained in the forward guide plate. The pins are offset to allow the D-rings to deploy as far as they can. The center part of the offset pins, which slide in the grooves of the forward guide plate, keep the pins properly aligned. These pins can simultaneously push or pull the D-rings in unison. The pins and cam plate are also the primary means of retaining the D-rings. Each D-ring has a groove to slide in and provide lateral support.

Due to the high spin rate that artillery shells experience (approximately 200 rev/s), the D-rings could deploy themselves. Retracting the D-rings will require a motor and possibly some sort of spring

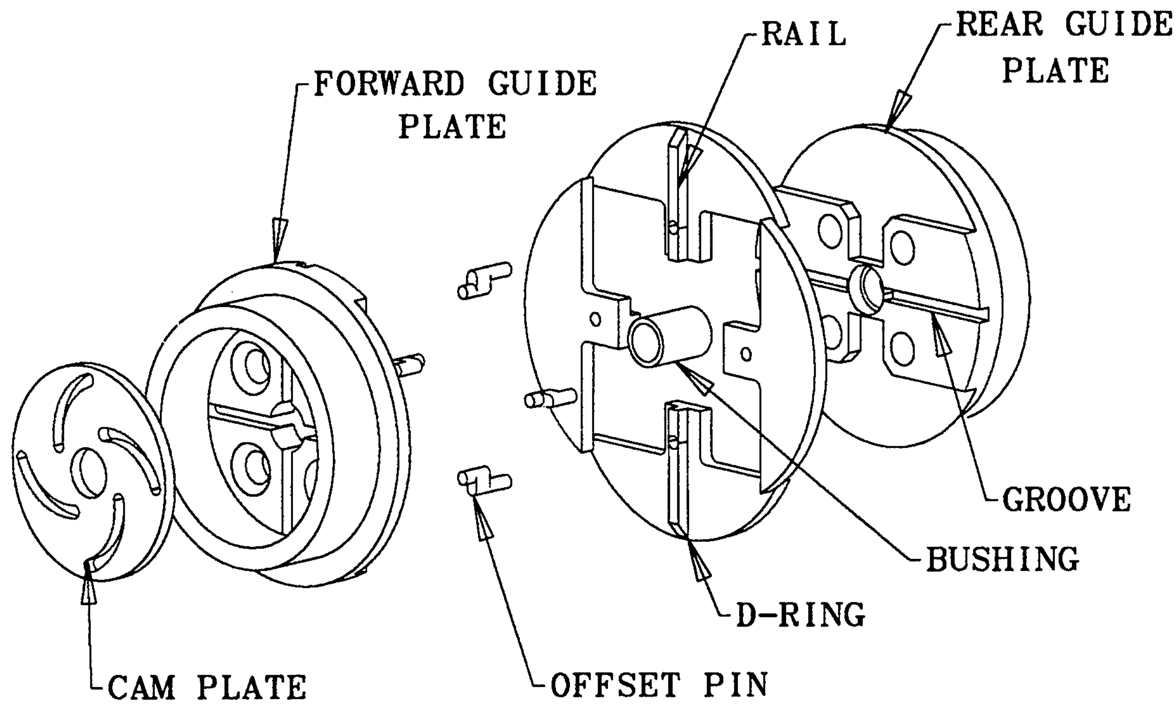

Figure 5. Cam actuation concept.

assistance. The spinning of the shell will impart a centripetal force on the D-rings. The forces were calculated using the following:

$$a_n = r\omega^2$$

$$G = a_n/g$$

$$F = WG$$

where:

a_n = centripetal acceleration

r = distance the shell's spin axis to the center-of-gravity of a D-ring

r_{closed} = 2.67 cm (1.05 in)

r_{open} = 3.56 cm (1.4 in)

ω = angular velocity, 1256.4 rad/s (200 rev/s)

g = gravitational constant, 9.81 m/s^2 (32.2 ft/s^2)

G = normalized acceleration

F = inertial load on the D-ring

W = weight of the titanium D-ring concept: 0.0255 lb (0.012 kg)

The centripetal force acting on a D-ring when it is retracted is 109.6 lb-force (487.5 N), and 146.1 lb-force (650.0 N) when extracted.

The torque required to retract a D-ring was estimated using the same inertial forces acting on the D-rings and the distance from the spin axis to the open and closed positions on the cam plate. Figure 6 displays the deployed and retracted positions of the cam plate. The following calculations were performed:

$$T = 4\mu F r$$

where:

T = torque

μ = coefficient of friction

r = distance to the extracted and retracted positions of the cam plate.

For a coefficient of dry friction of 1, the torque required to retract the D-rings at the extracted position is 211.6 in-lb. The coefficient of dry friction of 1 is reasonable for various steels. Since lubrication is difficult to maintain when the mechanisms are spinning at 200 Hz, a means of reducing friction would be to use slipperier materials. If the coefficient of dry friction were 0.04, which is the coefficient of dry friction of Teflon, the required torque at the extracted position would be 8.5 in-lb, or 135.4 oz-in. The reduction of friction is essential in decreasing torque. In addition to controlling friction, possibly some sort of clock spring that would be preloaded could aid in further reducing torque. If the torque is minimized, then, conceptually, a small, g-hardened electrical motor could actuate the cam plate.

2.4 <u>Volume for Components</u>. For this concept, the total volume for components is 9.9 in^3 (162.2 cm^3). This volume, as seen in Figure 7, is broken down into two parts: forward and aft. The forward volume totals 5.9 in^3 (96.4 cm^3) and the aft volume totals 4.0 in^3 (65.5 cm^3). These volumes are at a premium.

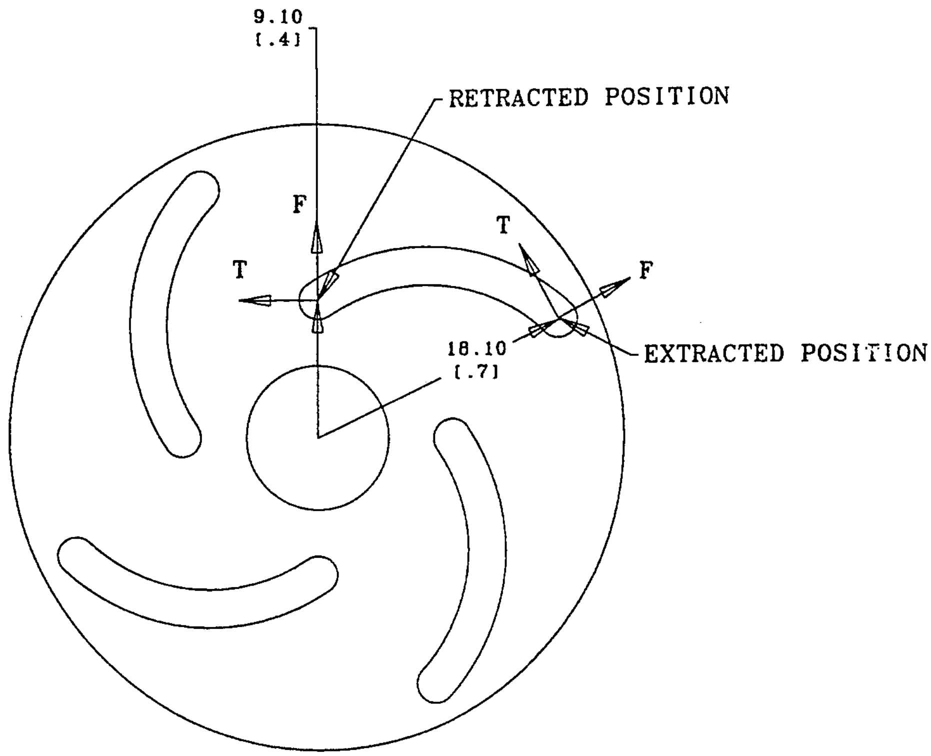

Figure 6. Deployed and retracted positions of the cam plate.

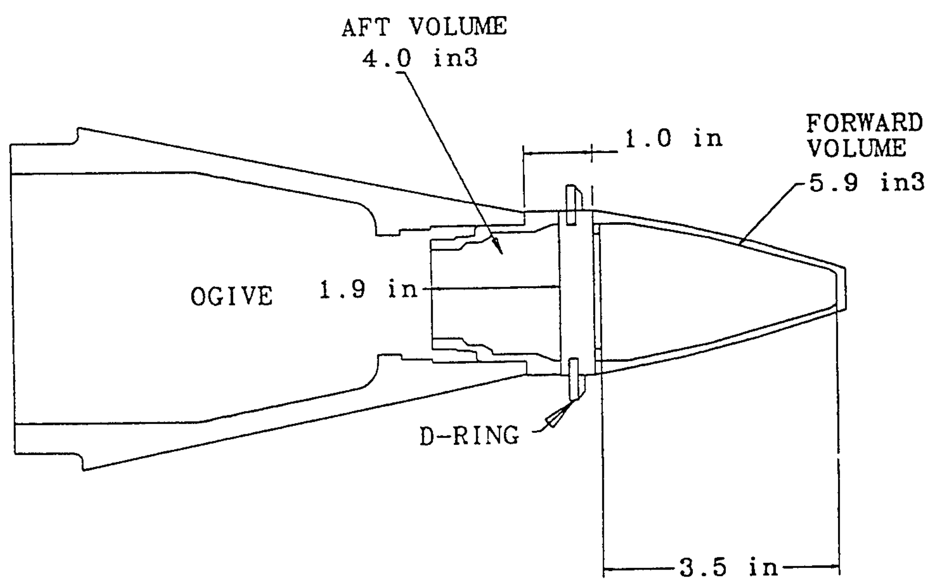

Figure 7. Volume: forward and aft.

To actuate the D-rings could require several cubic inches, depending on the deployment scheme of the D-rings. A "one-time" deployment scheme, where the D-rings are extracted only once, never to be retracted, would require less volume since a motor to drive the cam mechanism is not necessary. To retract the D-rings will require a g-hardened motor. This concept is similar to those proposed for LCCM canard and STAFF concepts. If the motor is DC electrically powered, then space would have to be allowed for extra power sources. If the motor is DC electric and brushless, then extra volume is required for the supporting electronics which perform the brushless motors commutation. Table 2 is a list of motors from various manufacturers and designers. This table lists dimensions, weight, stall torque, and power requirements. Some of these motors are still being prototyped, and none of them are g-hardened at present.

3. DISCUSSION

A hypothetical LCCM D-ring module volume budget is featured in Table 3. The volume of the D-ring mechanism is excluded to focus on utilizing the forward and aft volumes. The volume required for a Transicoil motor, size 8, with commutation electronics and a gearhead would take up 1.6 in^3. That motor will require a power source that can produce 12 V and 0.3 A.

A meeting with the ARDEC Fuze Management Office determined that all projectiles will need a safe & arm (S&A), a display, prelaunch power, and inductive and manual settings. These volumes totaled 3.65–4.40 in^3 (Springer 1995). It is assumed that the fuze processing would be integrated into the GPS functions (Springer 1995) and that the GPS receiver antenna can be imbedded into the nonmetallic ogive of the fuze so that it requires very little volume. The volume left over for a power source and the GPS/IMU/CPU components can be determined by subtracting the total volumes of the volume budget from the overall volume of 9.9 in^3. Table 3 combines the power source and the GPS/IMU/CPU components into one. Considerig that the GPS/IMU/CPU makes up 3.5 in^3 (D'Amico 1995), one can see that the volume for a power supply becomes limited, especially in the multiple correction concept.

A possible power source could be a thermal battery that is 1 inch in diameter × 1.75 inch in length yielding a volume of 1.4 in^3. This battery is capable of producing 15 V and a current ranging between 1–4 A. However, the volume for this battery is restrained to a cylindrical shape. Other possibilities are batteries currently being developed under the Hardened Subminiature Telemetry and Sensor Systems (HSTSS) program which have high power to volume ratios and are conformable to various geometries.

Table 2. Motor Characteristics

Maker	Model	OD (in)	Length (in)	Stall Torque (oz-in)	Power (W)	Voltage (V)	Current (A)	Speed (rpm)	Weight (oz)	Comments
KollMorgen[a]	QT-1207	1.5	0.5	20.0	81.8	variable	variable	3644.3	2.3	brush
KollMorgen	T-1242	1.5	1.0	25.0	55.0	variable	variable	1928.9	5.5	brush
KollMorgen	QT-1217	1.5	1.0	50.0	165.0	variable	variable	2557.3	5.5	brush
KollMorgen	00704	1.5	1.9	290.0	273.6	24.0	11.4	2500.0	8.4	brushless
Versatron	concept	1.5	2.0	12.0	140.0	28.0	5.0			brush
Versatron[b]		1.3	2.0	56.0	1950.0	130.0	15.0			brushless
Versatron[c]	concept	1.0	2.0	56.0	1950.0	130.0	15.0			brushless
Transicoil[d]	size 5	0.5	2.3	677.9	4.0	12.0	0.3	15.0	4.8	brushless
Transicoil[d]	size 8	0.8	3.0	288.0	4.5	12.0	0.3	100.0		brushless
Transicoil[e]	size 13	1.3	2.2	6.3	62.5	50.0	1.3	20000.0	7.2	brushless

[a] All motors are frameless, gear heads are not a standard option. High-volume manufacturing is not readily available. If KollMorgen were to produce 100,000 units, the unit price would be $25–$50.
[b] This motor already exists in an unhardened configuration.
[c] Versatron can add gear heads, but they will require more volume. Commutation electronics will require volume.
[d] Transicoil motors, with gear heads, will be running at about 20–30% efficiency. Commutation volume = 0.2 in^2.
[e] This motor does not have a gear head.

Table 3. Hypothetical LCCM D-Ring Module Volume Budget

	Single Correction (in^3 [cm^3])	Multiple Correction (in^3 [cm^3])
Fuze (no. S&A):	3.25	3.25
S&A:	0.75	0.75
Motor/Gearhead	N/A	1.6 [26.2]
GPS Receiver Technology (GPS/IMU/CPU)/Power Supply	5.9 [96.7]	4.3 [70.5]
TOTAL	**9.9 [162.2]**	**9.9 [162.2]**

4. CONCLUSION

Considering the available technologies and volume contraints, it appears that an LCCM D-ring range correction concept, with a single deployment scheme, is a distinct possibility without requiring aggressive technologies or high-risk approaches. In addition, the single deployment scheme shouldn't require much power since it does not require a motor to deploy the D-rings. The efficiency of the use of the volume for electrical and mechanical components for a multiple correction will be crucial.

To make the multiple correction D-ring module a viable concept, all technology areas (fuze, GPS, and the motor) would need to be substantially smaller. The future predicts that electronics and motors will get smaller and more efficient. As technological advances occur, the possibility of a multiple correction D-ring module should not be far off in the future.

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